Overview

AeroPropulsoServoElasticity
Fundamental Aeronautics – Supersonics Project

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Overview of APSE Propulsion Team/Task

- **Team: All NASA GRC** (2FTE's)
  George Kopasakis
  Joseph Connolly
  Nulie Theofilaktos
  Jeffrey Chen

- **NRAs**
  -- Past no NRA's
  -- New NRA Announcement this Spring

- **Type of Studies Conducted**
  -- So far Analytical Studies (TRL 1-3)

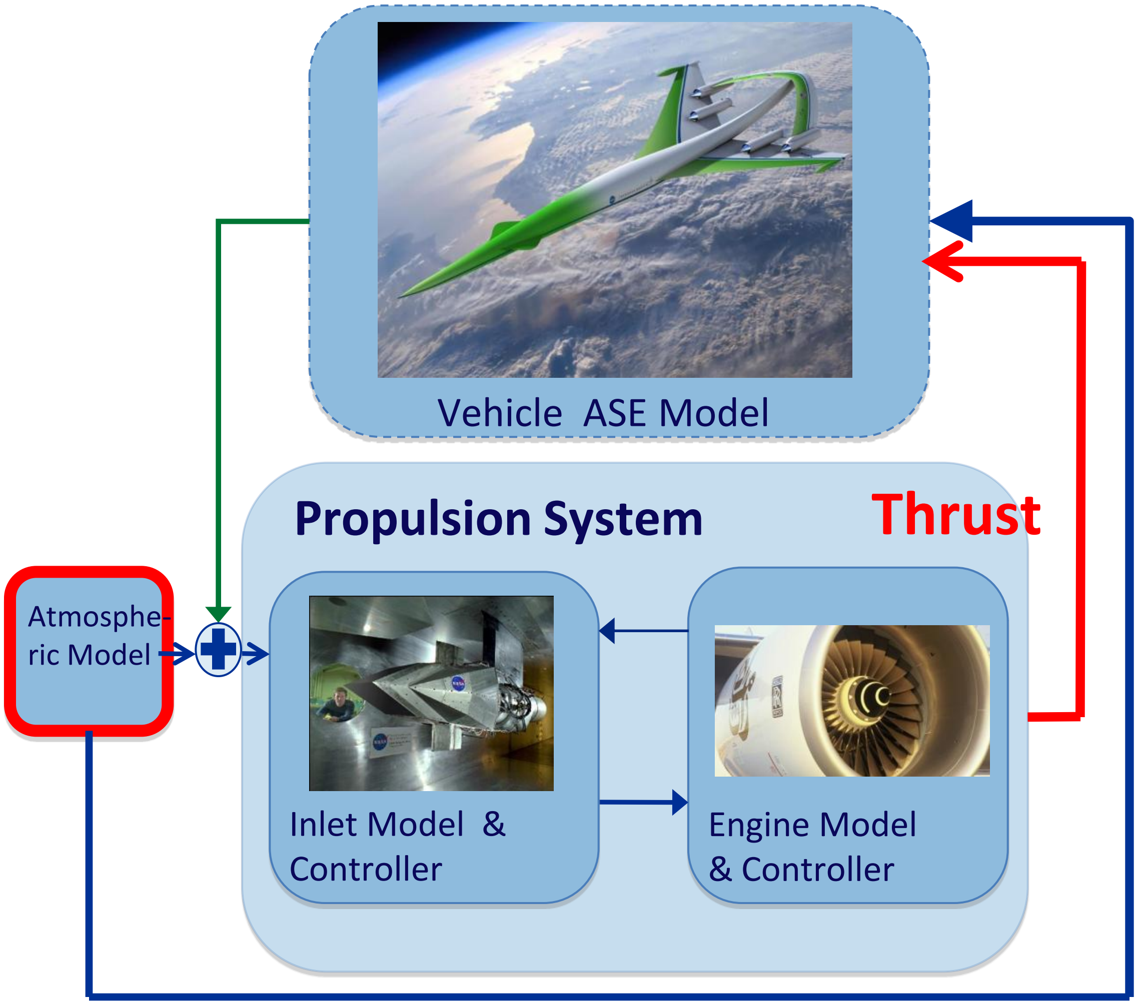
Project Challenges

- **The Supersonics Project aims to conduct fundamental research necessary to develop the technologies for supersonic transports**

- **As such the project identified several technical challenges**
  -- Among these challenges are also
    - **Performance challenges**, AeroServoElasticity (ASE) & Aero-Propulso-Servo-Elasticity (APSE) analysis and design

    - **Efficiency challenges**, including supersonic cruise efficiency

Objective
AeroPropulsoServoElasticity (APSE)



- Integrated Modeling &Controls Design
- Vehicle Stability
- Ride quality

- Cruise Efficiency

Design and Analysis

Integrated APSE Model
(NASA GRC in collaboration with NASA LaRC)

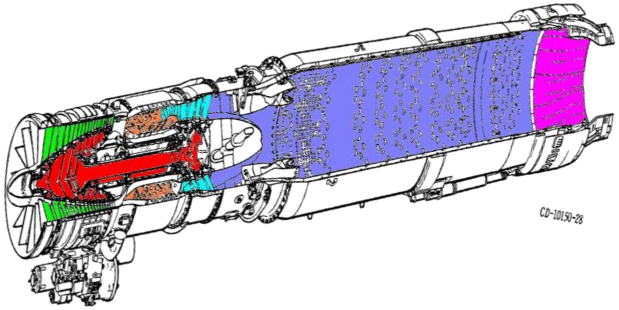
Approach - Propulsion Modeling

Engine

- Based on component gas lump volume dynamics and performance characteristics & separately stage-by-stage – reported in 2009 WorkShop (2009 WS)

  -- Developed Nonlinear and linear propulsion system models turbo jet (J85-13 engine) and turbofan – 2009 WS

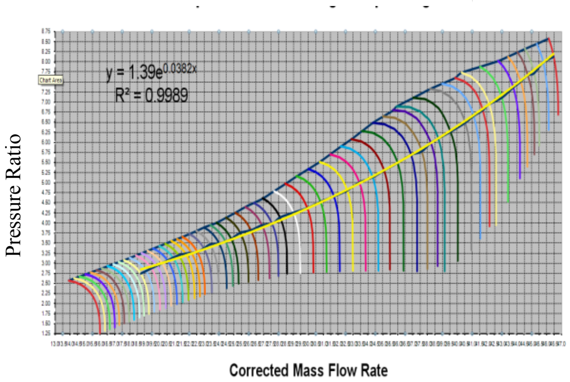
  -- Developed 1st version of N+3 variable cycle engine model



$$\frac{\partial}{\partial t}(\rho_s A) + \frac{\partial}{\partial x}(\rho_s A v) = 0$$

$$\frac{\partial}{\partial t}(\rho_s A v) + \frac{\partial}{\partial x}(\rho_s A v^2) = -Ag\,\frac{\partial P_s}{\partial x}$$

$$\frac{\partial}{\partial t}(\rho_s A u_t) + \frac{\partial}{\partial x}(\rho_s A v H) = 0$$



- Derived methodology for developing control schedules (J85-13)

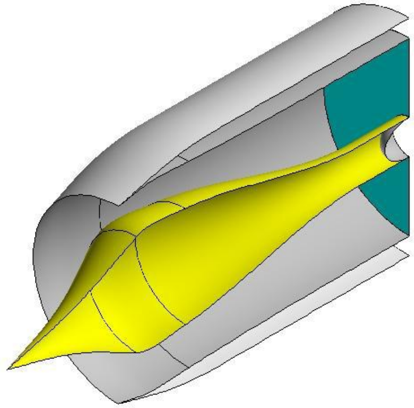
  -- For compressor operating line (2009 WS), and

  for exit nozzle area

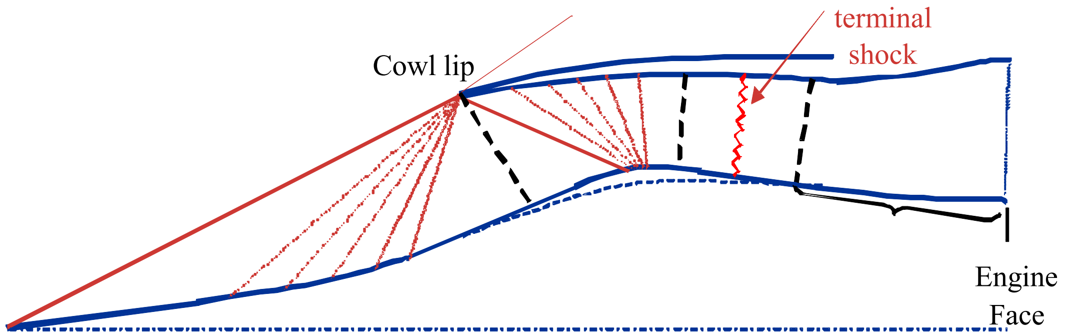
Approach- Propulsion Modeling

Inlets & Nozzles

- Initially developed linear mixed compression inlet models utilizing LAPIN (legacy Fortran code) – 2009 WS
- **Inlets** - Quasi 1-Dimensional (1D) Computational Fluid Dynamics (CFD) and Compressible flow w/ variable geometries

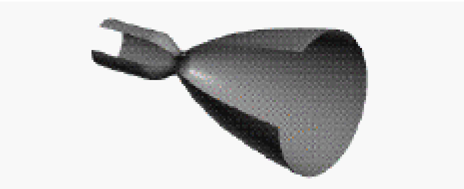


Axisymmetric External Compression inlet



Mixed Compression Inlet Diagram

- **Nozzles –** CFD based on MacCormack method

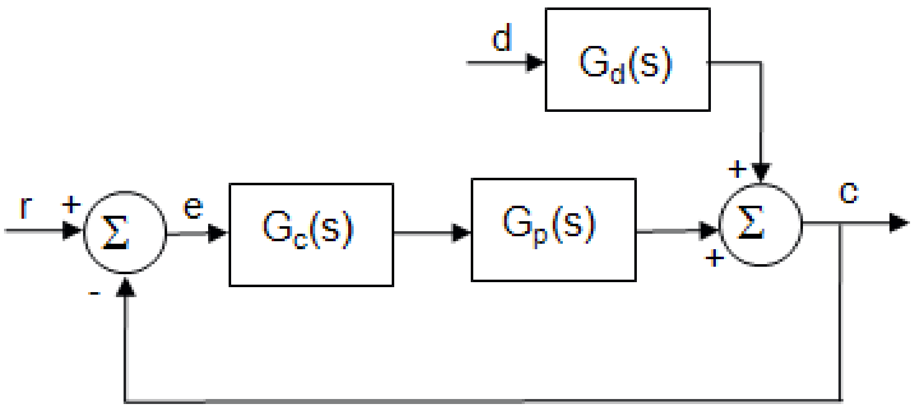


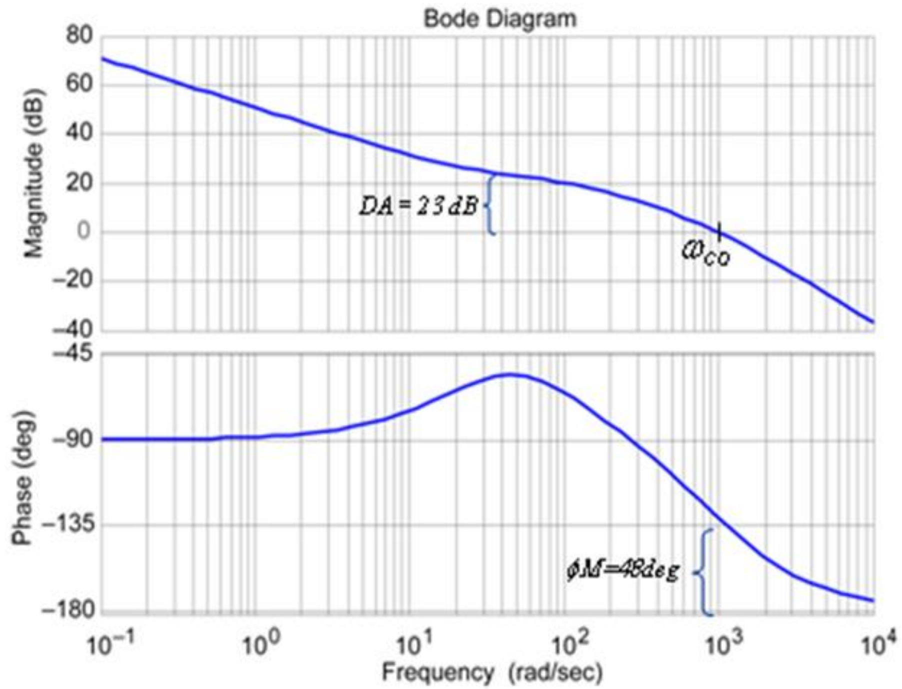
Convergent–Divergent (CD) Nozzle

Approach- Propulsion Controls

Feedback Controls Design – 2009 WS

- Based on feedback controls loop shaping design developed in this task
  - -- Relates hardware performance to design requirements
  - -- Maximizes control system performance



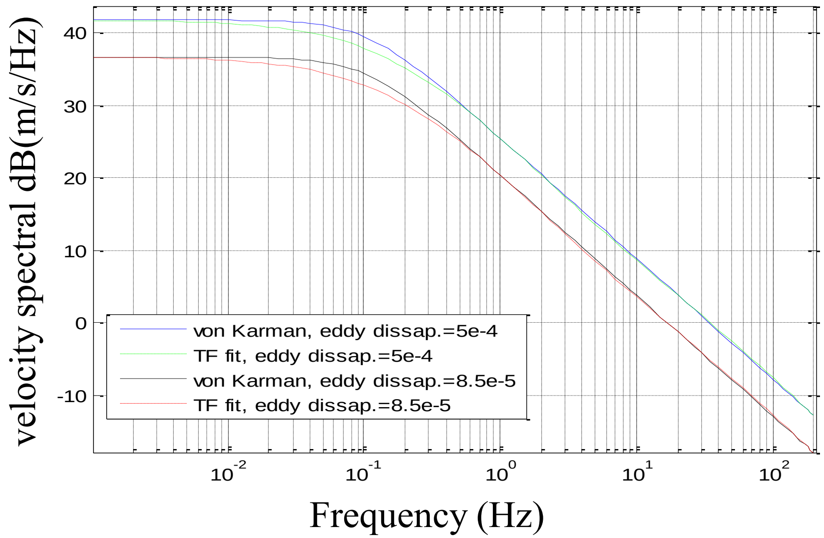


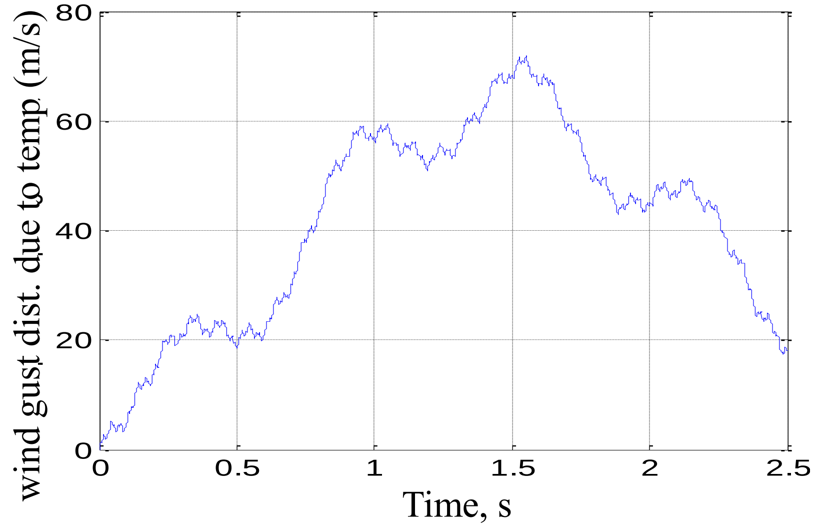
- Methodology used to design engine fuel actuation controls of linear and nonlinear propulsion system
- Also to design shock position controls for a supersonic inlet

Approach Propulsion Disturbance

Atmospheric Turbulence – 2009 WS

- Developed atmospheric turbulence models (wind gust, temp, pres)
  -- More accurate than existing models by ~ 7dB/decade
  -- Modeling fractional order nature of atmospheric turbulence



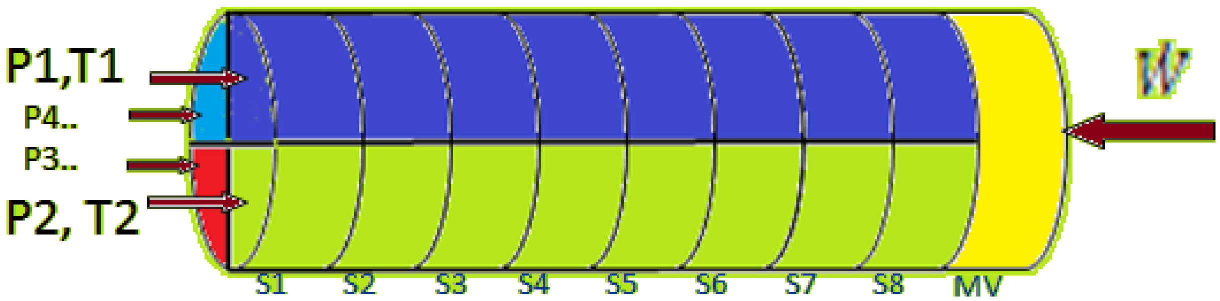


- Also need to develop disturbance models for AeroServoElastic, Pitch, Yaw and Roll

Approach Propulsion Modeling for Distortion And Boundary Layer Separation

Distortion

- By developing parallel flow path component models
  - -- Started with compressor utilizing stage-by-stage, 2D Euler in cylindrical coordinates
  - -- In the future extend to model fans and inlets



Parallel Flow Path Compressor Model

Boundary Layer

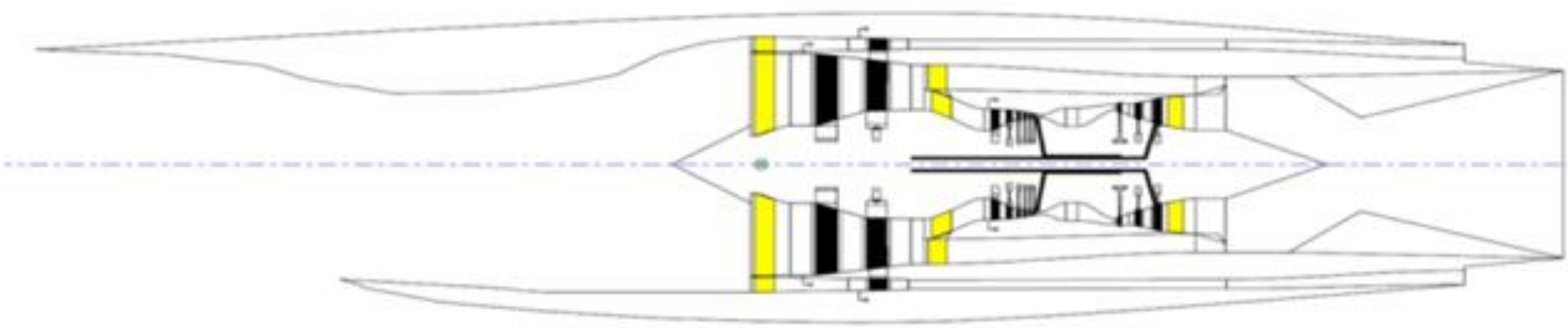
- May model by including effective area in the dynamics, else it would require more than 1D

Variable Cycle Propulsion System Studies

- Dual Spool variable cycle – High bypass at low altitudes to low bypass high altitudes

- Noise abatement for overland flight
  -- Through external bypass & through nozzle design

- Modeling approach same as with J85-13 approach except this engine has additional components and flow paths



Publications

1. Kopasakis - Feedback Control Systems Loop Shaping Approach with Practical Considerations, NASA/TM-2007-215007

2. Kopasakis et al. - Volume Dynamics Propulsion System Modeling for Supersonic Vehicles, GT2008-50524, NASA/TM-2008-215172

3. Connolly et al. - Turbofan Volume Dynamics Model for Investigation of Aero-Propulso-Servo-Elastic Effects in a Supersonic Commercial Transport, AIAA-2009-4802

4. Kopasakis et al. - Shock Positioning Controls Design for a Supersonic Inlet, AIAA-2009-5117

5. Kopasakis et al. - Volume Dynamics Propulsion System Modeling for Supersonic Vehicles, *Journal of Turbomachinery* (Vol. 132, October 2010)

6. Kopasakis - Atmospheric Turbulence Modeling for Aero Vehicles- Fractional Order Fits, NASA/TM-2010-216961

7. Kopasakis - Modeling of Atmospheric Turbulence as Disturbance for Control Design and Evaluation of High Speed Propulsion, GT2010-22851

8. Connolly et al. – Loop Shaping Control Design for a Supersonic Propulsion System Model Using QFT Specifications and Bounds" AIAA-2010-7068

9. Connolly et al. - Nonlinear Dynamic Modeling and Controls Development for Supersonic Propulsion System Research, AIAA 2011-5635.

10. Kopasakis - Modeling of Atmospheric Turbulence as Disturbance for Control Design and Evaluation of High Speed Propulsion, *Journal of Dynamic Systems* (vol. 134, issue 2, 2012).

11. Kopasakis et al. - Quasi 1D Modeling of Mixed Compression Supersonic Inlets, AIAA 2012-0775.

12. Kopasakis et al. - Quasi One-Dimensional Unsteady Modeling of External Compression Supersonic Inlets, AIAA, JPC, 2012 (pending).